Studying Gamma-ray Burst Progenitors under the NASA Swift Guest Investigator Program

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We have been funded to study gamma-ray burst (GRB) progenitors for the past 3 years. Each year, the collaborators, generally postdocs who work with Chris Fryer, change, as does the exact emphasis of the project when these postdocs take positions elsewhere. Last year's project was led by Chris Fryer, Patrick Young, and Gabriel Rockefeller. Gabriel is continuing a Director's postdoc here at LANL under Aimee Hungerford, CCS-2.

In this year, we have made considerable progress understanding the progenitors of long-duration GRB. We finished five papers [1,2,3,4,5] since November 2006 studying GRB progenitors, with six additional papers [6,7,8,9,10,11] studying physics relevant to GRB progenitors; studies either of massive-star collapse, supernova explosion or fallback, or binary properties. We led a comprehensive review of both the theory and observations that can be used to constrain the progenitors of GRBs [2]. In this work, which required the agreement of 17 scientists in the field, we surmised that binary GRB progenitors match the current set of data much better than single star models, even the rotationally induced mixing models [12]. At this point, we are reasonably convinced that the primary progenitor for long-duration GRBs requires a binary, and we will continue to focus our work on binary progenitors. This major review led to two very important lines of new research: the difference between black hole formation scenarios and the importance of understanding population synthesis uncertainties to make detailed observational comparisons.

First, our detailed study of the observational constraints led to a more focused study of long-duration GRB progenitors [3], discovering that the observations already can help us distinguish between systems that form black holes after the launch of a shock, fallback black holes, versus those systems forming black holes directly. Theory argued that some fallback black hole systems would not form GRBs if the fallback accretion rate is too low, but no firm predictions have been made, and some GRB scientists have put forth models with very low accretion rates.

Observations may be able to shed some light on this subject. Using metallicity and red-shift observations of GRBs, we found that the number of GRBs from fallback black holes is limited to a few percent of the currently predicted fallback black-hole rate, suggesting that most fallback systems do not form the GRBs in our observed sample. Our first study in this topic was fairly simple, but we do not believe the main result discussed here will change with new observations. One of the projects for this year is to determine other observational constraints distinguishing between fallback and direct-collapse GRBs to confirm or deny our claim. One such effort stems from our realization that fallback black hole GRBs have different nucleosynthetic yields and associated supernova light curves than direct collapse black holes [1,4]. These discoveries also led us to develop new studies of collapsar progenitors and supernova shock propagation to better understand fallback [6,7,8,9].

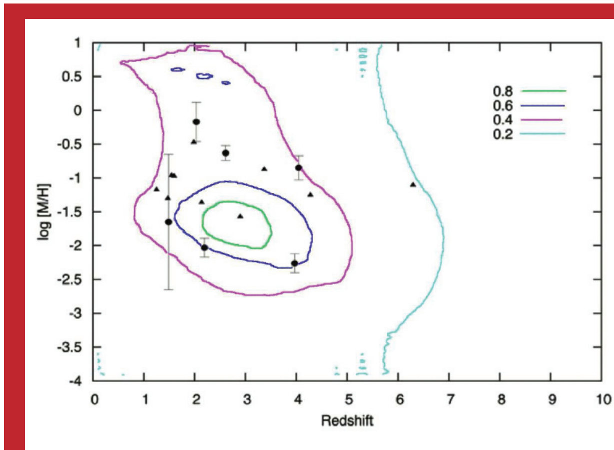

Fig. 1. Number of GRBs from a combination of all the direct-collapse black holes with 2% of the total number of fallback black hole systems. Contours are plotted for bins with 20, 40, 60, and 80% of the peak number. If fallback black holes are dominant GRB progenitors, the average metallicity would be higher and the redshift lower. The rotationally induced mixing model can not explain GRBs with metallicities above 0.1 solar.

Our review also helped us focus on some of the crucial uncertainties in studying binary populations that must be understood before making more direct constraints to the observations. We have studied in more detail the role of tidal effects in binaries [5] and wrapped up some observational studies of initial parameters, mass, and separation distributions for massive binaries [10,11]. We believe that if we can better understand the progenitors of normal type Ib/c supernovae, which our review [2] argued were also produced in binaries, we may gain some insight into the progenitors of GRBs. We have also done some type Ib/c population synthesis calculations [2,11].

We are currently on cycle 3 Swift funding. This funding covered work by Patrick Young examining aspects of GRB progenitors. It will also fund the work by Gabriel Rockefeller studying how angular momentum affects the fate of stellar collapse. Preliminary work (Fig. 2) on this showed that if the specific angular momentum in the material is too low, even though a disk forms, it is still unstable and unlikely to make the focused jets seen in observations. The nominal average angular momentum required to make a stable disk is $10^{17} cm^2 s^{-1}$, higher than that assumed in many population studies. This work has yet to be published, and we will spend some time with our current funding finishing this paper. We will also finish incorporating magnetohydrodynamics capabilities into our SNSPH [13] code to get an estimate of the role of magnetic fields in this collapse. Several other groups [14,15] have done some work in this area, and we will be able to compare our results with their work.

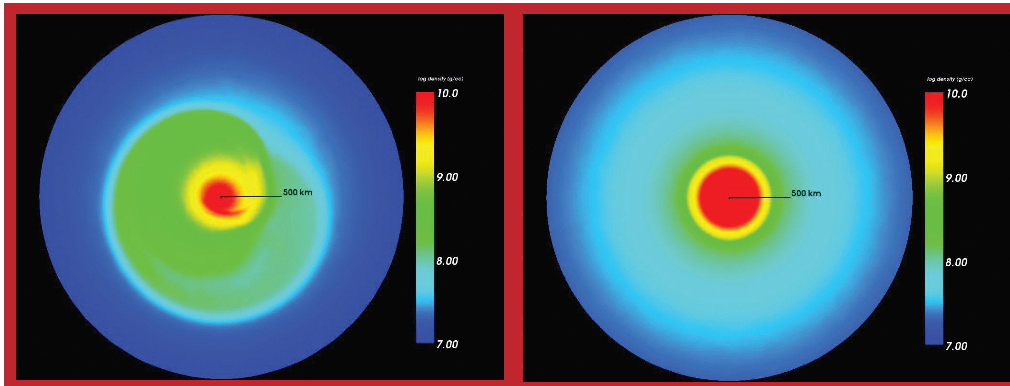

Fig. 2. Plots looking down the angular momentum axis (z-axis) of two collapse calculations of a 60 solar mass star at 0.44s: one with an average specific angular momentum ~5x1016cm2s-1 (left), the other with twice that angular momentum (right). To get a stable accretion disk that can develop focused jets, we required this latter (1017cm2s-2) high specific angular momentum.

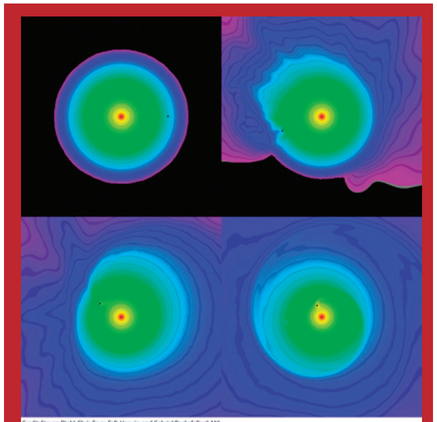

Fig. 3. Simulation of the common envelope evolution of a brown dwarf within a Red Giant star using our SNSPH code [15,16].

We will also spend part of the time of our current funding adapting the SNSPH code to better model the mass transfer in binaries. Steven Diehl, a postdoc at LANL, has already begun an effort to model low-mass binaries under an internal LANL effort led by F. Timmes to study hydrogen-deficient stars. Figure 3 shows some preliminary results from this effort, the common envelope evolution of the white dwarf (WD0137-049) brown dwarf binary [16,17]. As part of this effort, we have finished much of the verification and validation of this modified code, paying particular attention to the accuracy of the gravity routine and the ability for our scheme to model angular momentum conservation.

With the progress we have made, we expect to renew this NASA funding and continue to contribute LANL excellence in GRB progenitors.

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